Electromagnetic Propagation

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LONG TERM GOALS

Develop electromagnetic propagation models for use in operational or engineering propagation assessment systems.

OBJECTIVES

Develop an advanced unified hybrid radio propagation model based on parabolic equation and ray-optics methods for both surface-based and airborne applications. This model is named the Advanced Propagation Model (APM) and is the model used in the Advanced Refractive Effects Prediction System (AREPS). Resolve differences between current techniques used to model propagation effects under rough surface and strong ducting conditions.

APPROACH

We develop parabolic equation, ray optics, waveguide, and other models as necessary to produce both accurate and efficient models to be used in propagation assessment systems. In many cases we can use variations of existing models to achieve this goal, but sometimes completely new models are necessary. Once developed, these models are compared to other models and to experimentally collected propagation data for verification of accuracy. We stay abreast of other researchers' newest models by reading current literature, participating in propagation workshops, and attending conferences as appropriate. There is a strong international exchange of ideas and techniques in this area, as some important work is performed outside of the USA. This project is divided into two tasks: (1) Propagation Modeling, PI Amalia Barrios, and (2) Rough Surface Effects, PI Kenneth Anderson.

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Rama Janaswamy, formerly of the Naval Postgraduate School and now of Electrical and Computer Engineering Department, University of Massachusetts, investigates parabolic equation and rough surface effects theoretically.

WORK COMPLETED

PROPAGATION MODELING

A land clutter model was developed and implemented in the Advanced Propagation Model (APM). In collaboration with the EO IR Transmission and Radiance task (P.I. Stephen Doss-Hammel), both PE and ray optics techniques were investigated to develop a propagation model to account for refractive effects at infrared frequencies. APM contains the Discrete Mixed Fourier Transform (DMFT) algorithm, originally developed by the Applied Physics Laboratory at Johns Hopkins University (JHU/APL), to model a finite conducting boundary and a rough sea surface. Previously, APM contained a numerical instability problem, related to the DMFT algorithm, which produced erroneous results when modeling rough sea surface effects for combinations of high wind speeds and high frequencies. Prof. Janaswamy developed an alternate formulation of the DMFT, which has all but eliminated these problems. The improved algorithm has now been implemented in APM

ROUGH SURFACE EFFECTS

A mission plan was executed for the Rough Evaporation Duct (RED) experiment, 20 August to 18 September 2001. *R/P FLIP*, moored some 10 km offshore of Oahu, served as the primary meteorological data collection platform and also served as a terminal for both RF and EO propagation paths. Receiver sites were at both the Marine Corps Base Hawaii (RF path) and at the Malaekahana State Park (EO path). Figure 1 shows the arrival of *R/P FLIP* at Pearl Harbor.

Figure 1. Office of Naval Research's (ONR) FLIP (Floating Instrument Platform) is towed into Pearl Harbor Monday afternoon by USNS Sioux (ATF 171) (not pictured). While in Hawaii FLIP will support two ONR scientific research programs, the Rough Evaporation Duct. (This figure and caption are from the Hawaii Navy News http://www.hnn.navy.mil *Volume 26, Issue 32 Aug. 17, 2001)*

RESULTS

PROPAGATION OVER TERRAIN

We found the PE model to be extremely numerically intensive at IR frequencies and could not easily provide the angle-of-arrival of the field intensity at a receiver height of interest. Knowledge of the angle-of-arrival is important in determining target location for use in imaging systems such as IRSTs. The ray optics technique proved to be simpler, faster, and could easily provide angles-of-arrival at any field point. The ray optics method was the model of choice in the refractive analysis of infrared transmission data taken during a field experiment in Nov 96. Overall results concluded that refractivity, and hence, a propagation model to account for these effects must be included in any EO/IR assessment system for low altitude applications. A report has been written describing these results and will be submitted to Applied Optics.

The alternate formulation of the DMFT is a major improvement in our capability not only to model forward-scatter propagation, but in also computing clutter as this is directly dependent on the forward-scattered field.

ROUGH SURFACE EFFECTS

The major efforts for this year have been preparing for and executing the RED experiment. As of the writing of this report, the experiment was concluding.

IMPACT/APPLICATIONS

The goal of this work is to produce the best possible hybrid radio propagation model for incorporation into U.S. Navy assessment systems. Current plans call for APM to be the single model for all applications. As APM is developed it will be properly documented for delivery to OAML, from which it will be available for incorporation into Navy assessment systems. The extension of APM to model sea and land clutter will improve operational assessments and also provides modeling support for a related project pursuing the concept of extracting refractivity profile information from radar clutter returns.

TRANSITIONS

APM Version 1.3 now accounts for rough sea surface effects, sea clutter, and land clutter. APM was transitioned into the Tactical EM/EO Propagation Models Project (PE 0603207N) under PMW 155 which has produced the Advanced Refractive Effects Prediction System (AREPS). Academia and other U.S. government also is utilizing APM/AREPS. A recent example of the later is the Yuma Airways Sector of the Federal Aviation Administration using AREPS to provide insight to a solution for the FAA's problem of losing radar aircraft tracks in the Western Pacific region.

RELATED PROJECTS

This project is closely related to the synoptic and mesoscale numerical analysis and prediction projects pursued by NRL Monterey and the Coastal Variability Analysis, Measurement, and Prediction (COVAMP) project which pursue providing the refractivity inputs for APM. This project is also related to the Remote Refractivity Sensing project under ONR 321SI in providing fast-running, high-fidelity forward propagation modeling used in the RRS inference techniques. The transition target for this project is the Tactical EM/EO Propagation Models task under PMW 155 and the Oceanographic and Atmospheric Master Library. Tri service coordination is conducted under the Technology Area Review and Assessment.

SUMMARY

This project has developed a hybrid ray optics/parabolic equation propagation model for assessing the effects of the atmosphere on electromagnetic emissions in the range of approximately 100 MHz to 50 GHz for both surface based and airborne transmitters. Atmospheric effects include varying terrain elevation, range-varying refractive structure, and atmospheric absorption. One of the most significant deficiencies of this model is the lack of a validated (or even an agreed upon) method to account for wind-roughened sea surface effects at over-the-horizon ranges, especially under strong surface ducting conditions, in the parabolic equation model. This deficiency led to us to undertake an experimental and analytical program to develop a validated rough sea surface submodel for APM. The Rough Evaporation Duct (RED) experiment just completed in the Hawaiian Islands is the field measurement phase of this task.

PUBLICATIONS

Anderson, K., The Rough Evaporation Duct (RED) Experiment, National Radio Science Meeting, URSI, 8-11 Jan 2001, p. 265.

Barrios, A., Doss-Hammel, S., Zeisse, C., “Abrupt Changes in Infrared Signal Intensity Due to Refractive Effects”, National Radio Science Meeting, URSI, 8-11 January 2001, p. 264.

Barrios, A., “Estimating Refractivity from Land Clutter: Another Look at a Simple Approach,” International Geoscience and Remote Sensing Symposium, IGARSS 2001, Sydney, Australia, 9-13 July 2001.

Janaswamy, R., “Propagation over a non-constant immittance plane,’’ to appear in *Radio Science*, 2001.

Janaswamy, R., “Propagation of line source fields over a non-constant admittance plane,’’ Paper # 7P.3, Joint IEEE Int’l Symposium on Antennas & Propagation/URSI Meeting, Salt Lake City, July 2000.

Janaswamy, R., “Rigorous propagation modeling over rough sea surface by the parabolic equation,’’ National Radio Science Meeting, URSI, 8-11 Jan 2001, p. 93.

Jha, R.M. and R. Janaswamy, “Low Grazing Angle Radiowave Propagation over Sea Surfaces,” submitted to Electronics Letters, Aug. 2001.

Zeisse, C., Barrios, A., Doss-Hammel, S., de Leeuw, G., Moerman, M., de Jong, A., Frederickson, P., Davidson, K., “Low Altitude Infrared Propagation Over the Ocean: A Refractive Analysis”, 2001, *to be submitted to Applied Optics*.